

Development of a Multicore Power System Simulator for Ship Systems

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Abstract—An important impediment to using widely available software to simulate the behavior of advanced power systems for electric ships is that the simulation time is too long to be practical. Consequently, the Center for Electromechanics at the University of Texas at Austin (UT-CEM) is developing a multicore power system solver to simulate large shipboard power systems. In its first year of development, the focus is on testing CEM's solver (*CEMS*) for accuracy. This paper presents an overview of the major traits of *CEMS*, and compares its simulation results to the well-known commercial power system simulator *SimPowerSystems*. Preliminary results show that accuracy is maintained and improved in specific test cases.

I. INTRODUCTION

As the all-electric ship program continues to progress from the conceptual stage toward practical implementation, the need for accurate modeling and simulation of its electrical power system has become more apparent. The large assortment of loads encountered on a warship, ranging from continuous duty loads to highly intermittent duty loads, makes it imperative to understand how the loads can be integrated in the shipboard power system and how they will interact dynamically with each other, as well as with the available power sources. Furthermore, the increased presence of power electronic stages, especially at the interface between the ac and dc zones of the system, requires more stringent control methods, both at the local and global level, thus adding to the complexity of the system.

Under the sponsorship of the Office of Naval Research, researchers at the University of Texas Center for Electromechanics (UT-CEM) have made an attempt to model a notional electric ship with a collection of different loads. This effort resulted in the development of a relatively large power system model, using *SimPowerSystems* [1], for a ship system supporting several load types. Although the effort produced usable and interesting results, the large power system model highlighted a major challenge: even under the assumption of a simplified architecture, the power system complexity poses strong computational demands on desktop computers, which results in unbearably long simulation run-times. In fact, it was not unusual to wait one week for calculations covering only six seconds of simulated data. This issue involving execution time

in commercial power system simulators [1],[2] is well known throughout the Navy and its shipyards.

While efforts to speed-up the simulation time of shipboard power systems models are not new, they are not widely available or come at a cost. For example, in [3], the latency insertion method was used to partition a large, notional electric shipboard power system into subsystems. Although speed gains of 14x were reported on a multicore computer, VTB [4] is required as the user-interface. The current approach is to try to achieve the same acceleration using more conventional interfaces to reduce training costs. An additional widely known solver is Opal-RT's ARTEMIS [5], currently capable of importing *SimPowerSystems* schematics and solving large shipboard power systems in real-time when using their target hardware. A solution as such, however, would require the acquisition of costly specialized hardware and would not be accessible to other members of the ship research community. Power system models in the ship community already exist in *SimPowerSystems* or PSCAD [2], and remaining in such environments reduces training costs.

This paper presents an overview of UT-CEM's effort to develop fast power system simulations for Navy entities: a multicore power system solver called *CEMS*. Two traits make *CEMS* highly attractive: compatibility and speed potential. Compatibility comes from using *SimPowerSystems* as the user interface, which will allow users to retain *existing* models and solve them in *CEMS*. Speed is sought via power system partitioning and proper exploitation of multicore technology, which is now available on desktop computers.

Section II presents traits that make *CEMS* an attractive solver. Section III presents major tiers internal to the solver under development. Section IV presents case studies to demonstrate the solver's accuracy in specific cases.

II. MOTIVATION

Compatibility and speed are of primary concern, to UT-CEM. These characteristics have been deemed necessary to increase the wide spread impact of *CEMS*. An overview of these two traits follows

A. Compatibility

The life span of a program is strongly dependant on its usability. For this reason, UT-CEM decided to shun the development of a graphical user interface (GUI) for *CEMS*, and instead use the familiar *SimPowerSystems* as its GUI [6]. Use of an existing GUI circumvents several issues of new interface designs: development, maintenance, support, documentation, training, and porting existing models. These issues unnecessarily demand an exorbitant amount of staff-years.

Integration between *SimPowerSystems* and *CEMS* is depicted in Figure 1. After creating or opening *SimPowerSystems* models (.MDL file), users are currently able to solve select models as normal in *Simulink*—or—launch *CEMS* (.EXE file), import the .MDL file, and execute the simulation externally. Since *CEMS* is intended for *large* power system models only, users will be advised to simulate small models as normal. The simulation data produced by *CEMS* is in the form of .CSV files which can be plotted from most visualization environments.



Figure 1. *CEMS* imports *SimPowerSystems* models and solves outside of the *Simulink* environment. The results are output in .CSV files.

B. Speed

Several things are responsible for lengthy simulations, including single matrix formulations, system order, switch model, integration step size, programming efficiency, etc. These are *software*-based and controllable in the sense that their impact can be mitigated at a relatively low cost.

Because software-based reasons can be addressed at a relatively low cost, UT-CEM has embarked on the development of a multicore power system simulation solver named *CEMS*. The partitioning approach used by *CEMS* addresses the issue of single-matrix formulations which do not use the many cores available on desktop computers.

Consider the electrical network disconnection point partitioned by virtue of current source transportation [7] as shown in Figure 2. Before the separation, the boundary voltages were v_a , v_b , and v_c . The separation bisects these voltages as v_{a1} and v_{a2} , as v_{b1} and v_{b2} , and as v_{c1} and v_{c2} , respectively. This partitioning technique is known as node tearing [8-11], and is used by *CEMS*. (Details on solutions of this type can be found in [8],[12].)

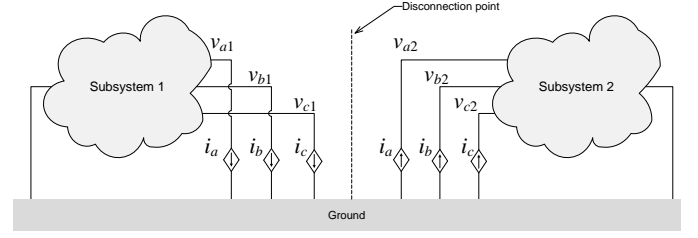


Figure 2. Partitioning method implemented by *CEMS*. Current sources are torn at the disconnection point shown.

Development of *CEMS* follows the spiral design approach depicted in Figure 3. Each stage is entered as the previous stage reaches satisfactory completion. This cycle is currently in effect and will continue until *CEMS* is available. As exemplified with case studies later, this paper is the result of the first accuracy assessment. Subsequent work by the authors will become available as *CEMS* progresses through the design cycle.

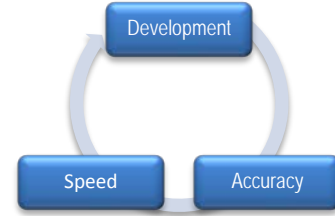


Figure 3. Software design cycle. As phases reach acceptable completion, the next phase is visited in clockwise order.

III. PROGRAM TIERS

CEMS executes several tiers before starting a simulation. Among these tiers, the major ones are discretization, partitioning, and simulation methodology.

Discretization in *CEMS* is based on root-matching [13] instead of trapezoidal integration. This choice stems from the fact that root-matching is not as sensitive to numerical chatter as is the trapezoidal rule [14],[15]. Although backward Euler integration is suitable for specific circuits [16], it is not difficult to show that its accuracy falls short of that of the trapezoidal rule.

Partitioning was explained at the electrical network level assuming the disconnection point location was known. In practice, determining the *number* and *location* of these disconnection points (for large power system models) is a difficult task [17].

Determination of the disconnection points in *CEMS* is carried out with graph theory. Before each simulation, *CEMS* creates a representative graph of the power system, where each vertex represents a power apparatus and each edge represents an electrical node. The graph is traversed and partitioned using *hMetis* [18], which has readily-implemented partitioning and

balancing heuristics [19] suitable for locating the disconnection points.

The simulation methodology consists of a multithreaded scheme [20] based on two-way signaling [21]. After partitioning the power system, each subsystem is appointed to an operating system thread. At each step of the simulation, each thread solves the electrical network equations of its respective subsystem, then waits for a synchronization signal. Shared-memory is used to exchange data between threads. This multithreading pattern is effective in multicore computers where data exchange does not require physical communication networks as observed in PC-clusters [22].

IV. CASE STUDIES

Three case studies demonstrate the accuracy of *CEMS*. Simulation results from these cases are compared to results obtained with *SimPowerSystems*. All simulations were executed using a time step of $\Delta t = 50 \mu s$, and using the fixed-step solver in *SimPowerSystems*.

Case 1) RLC circuit

This case shows that *CEMS* and *SimPowerSystems* yield identical results for purely sinusoidal circuits. Consider for example the RLC circuit [23] shown in Figure 4. An overlay of the current waveforms produced by *SimPowerSystems* and *CEMS* is shown in Figure 5. No discrepancy exists between the two results.

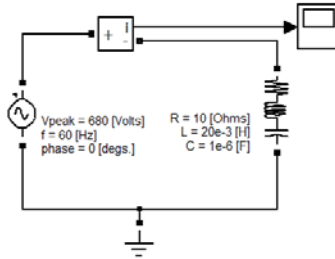


Figure 4. RLC circuit used for case 1.

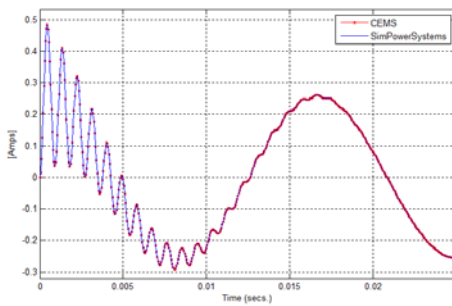


Figure 5. Current waveform overlay for case 1.

Case 2) Diode and RL circuit

This case shows that *CEMS* is insensitive to numerical chatter. Consider the diode and RL circuit shown in Figure 6

[14], where the snubber was made resistive to ensure real eigenvalues. When the diode turns off, the load's voltage oscillates around zero in *SimPowerSystems*, as shown in Figure 7. This fictitious oscillation, known as numerical chatter, is a well known problem of trapezoidal integration [15]. A close-up of this result is shown in Figure 8, where it can be seen that *CEMS* correctly brings the voltage to zero without oscillations.

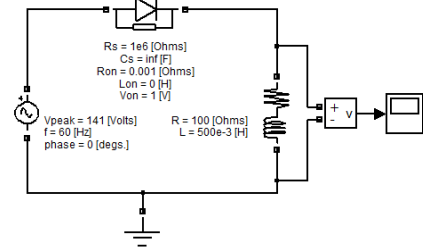


Figure 6. Diode and RL circuit used for case 2.

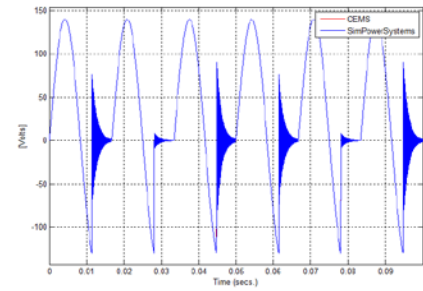


Figure 7. Voltage waveform for case 2.

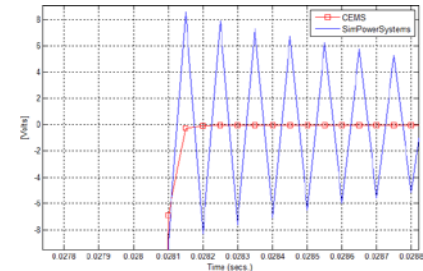


Figure 8. Close-up of the voltage waveform show in Figure 7.

Case 3) Three-phase rectifier

This case shows that *CEMS* does not experience the numerical chatter exhibited in case 2, even when partitioning a switching circuit. The three-phase rectifier circuit shown in Figure 9 was partitioned using the approach described for Figure 2. (For models of this size, the run-times of *CEMS* and *SimPowerSystems* are approximately the same.)

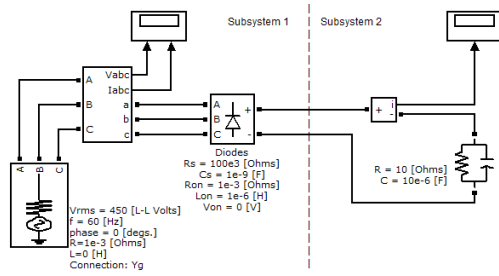


Figure 9. Partitioned three-phase rectifier circuit (case 3).

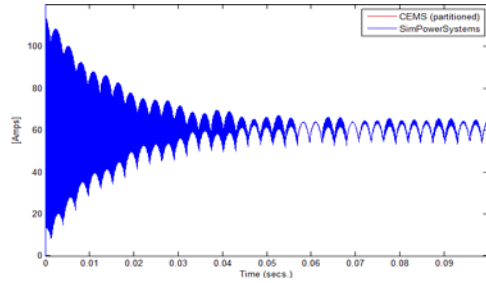


Figure 10. DC side current waveform.

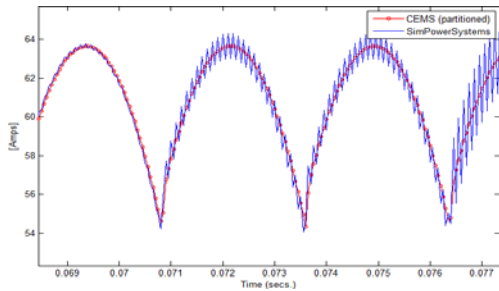


Figure 11. Close-up of current waveform shown in Figure 10.

As seen from the DC side current in Figure 10 and Figure 11, *SimPowerSystems* gives incorrect results as it uses trapezoidal integration. Although in *SimPowerSystems* these oscillations can be suppressed by using a variable-step solver, variable-step solvers are too inefficient in large model simulation to be practical. From Figure 11, the results provided by *CEMS* do not exhibit oscillations. Additionally, it was verified that the partitioned and unpartitioned results provided by *CEMS* agree with one another.

V. SUMMARY AND CONCLUSIONS

Compatibility and speed are at the core of UT-CEM's effort to develop a power system solver. Compatibility will allow users to retain existing *SimPowerSystems* schematics and optionally execute them in *CEMS*. Speed is sought by partitioning large power system models and using multithreading programming techniques to exploit multicore technology.

Accuracy is more important than speed. In this regard, considerable resources are currently allocated to ensure that the

results provided by *CEMS* are consistent with *SimPowerSystems*. Because the equation formulation and discretization approaches in *SimPowerSystems* and *CEMS* are different, some result discrepancies are expected. Among the case studies analyzed, of which some were shown in this paper, the results by *CEMS* are consistent, and in some cases, better than the results provided by *SimPowerSystems* fixed-step solver. (A comparison between *CEMS* and the variable-step solver in *SimPowerSystems* has not been made.) Since accuracy appears to be acceptable at this stage of the work, UT-CEM plans to move forward to demonstrate the increase in speed.

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